Available online at www.sciencedirect.com

ScienceDirect

Procedia Environmental Sciences 2 (2010) 1169–1179

Procedia
Environmental Sciences

International Society for Environmental Information Sciences 2010 Annual Conference (ISEIS)

Assessing changes of trophic interactions during once anthropogenic water supplement in Baiyangdian Lake

Ying YANG, He CHEN, Zhifeng YANG *

School of Environment, Beijing Normal University, Beijing 100875, PR China

Abstract

Baiyangdian, located in Hebei province, is the biggest freshwater lake in North China. Since the 1960s, due to increasing human activities and climate change, this area has suffered from markedly shrinking and drying up several times. In current situation, anthropogenic water supplement plays a very important role in maintain this wetland's existence and development, and from 1981 to 2003 this approach had been already carried out 15 times. But until now there is few study in the aspect of whole ecosystem level responded to anthropogenic water supplement. In this study we used Ecopath model to analyze the changes of ecosystem's structure and function in connecting with once water supplement event which started in middle September 2009. Based on field experimental data in September and October 2009, two mass-balance models of the Baiyangdian Lake were developed to compare differences in energy flow process, trophic composition and other system character indexes during this two periods. As the results show, from September to October, the biomass proportion of first trophic level distinctively increased but in higher trophic level this proportion declined, meanwhile the total primary productivity/total respiration (TPP/R) increased by 12.07%, the system omnivorous coefficient (SOI), Finn 's cycling index (FCI), and the average path length decreased by 4.16%, 20.13%, and 23.4% respectively. Most of the change directions of the indexes are contrary to the natural processes of ecosystem development, which meant that the interactions of organics are weakened, system maturity is degraded further and the ecosystem became more vulnerable to external disturbance after this time of anthropogenic water compensation.

Key words: Baiyangdian wetland; Water compensation; Food web structure; Ecopath

* Corresponding author:
E-mail address: zfyang@bnu.edu.cn.

1878-0296 © 2010 Published by Elsevier Open access under CC BY-NC-ND license.
doi:10.1016/j.proenv.2010.10.126

Introduction

Wetland is one of the most venerable ecosystems in the world (Brock and Vierssen 1992; Kusler 2000; Liu et al. 2006), and it plays an important role in providing water resources, controlling floods, and regulating regional resources. In recent years because of the increasing climate change and human activities, wetland degradation is widely remarkable, especially in arid and semi-arid areas (Liu et al. 2006).

For wetland degradation, water regime is regarded by many aquatic ecologists to be the key driving factor (Hart and Finelli 1999; Li et al. 2004; Poff et al. 1997; Puckridge et al. 1998; Richter et al. 1997). Changes to water regime may cause profound consequences. Compared with logic ecosystem, the water regime of wetland can be characterised by a pattern of flooding, drying or water level change and can be described according to when water level changes occur, how much, how fast and for how long (Roberts et al. 2000). Wetlands always have high biodiversity and are supported by flows from upstream rivers, but currently in the worldwide, many wetlands' natural water regime have been affected by dams and water management (Kingsford 2000), the man-made change of water regime is the major threat to the wetland functioning and is responsible for aquatic organisms' existence, biomass, life history strategies responses (Brock et al. 1999; Bunn and Arthington 2002). Many studies have focused on this aspect and water regimes are known to affect plant persistence (Brock 1991), vegetation communities (Haworth et al. 1999). macro invertebrates (Bjelke et al. 2005; Wantzen et al. 2008; Wantzen et al.), fish (Fischer and Ohl 2005), waterfowl (McIntyre 1994) and so on. Although recognition of the relationships among water regimes and biota factors is growing, the quantitative understanding or predictive models of ecosystem level responses to altered water regimes are still lacking (Coops et al. 2003).

Baiyangidan is the biggest typical grass-type shallow lake in North China Plain, this region is in the semiarid monsoon climate zoon, which lacks rainfall and the annual and inter-annual distribution is uneven, In addition, high population density and rapid development of industry and agriculture have aggravated water resources crisis further, make this area very fragile (Liu and Lin 2004). Since the 1960s, due to runoff interception result from dam establishment in the upper reaches and climate change in the zone, Baiyangidan have suffered from seriously water declined even dried up several times. And the severe ecological problems have drawn increasing attention of scientists, government officials and the public. How to improve the present conditions has become a burning question. In order to avoid the lake degradation, the conservancy department and the local government have undertaken anthropogenic water compensation several times, just from 1981 to 2003 this approach had been implemented 15 times to maintain the ecosystem (Liu 2005). But until now the quantificational information of biota changed before and after once water supplement is not enough. Moreover, few analysis try to summarize and integrate available observation data to obtain great insights into the whole ecosystem change. Ecological models are useful tools for survey at the whole ecosystem level, based on models, changes in the species relationships can be explored and the overall function of ecosystem can be compared (Heymans et al. 2004). Ecopath with Ecosim (EWE) is an ecosystem-based analysis software, currently has been widely applied in more than 100 aquatic ecosystems including ocean, lakes, reservoirs, ponds across the world (Christensen et al. 2008). EWE is constructed based on energy balance of food web, which can be used to study the system scale, stability and maturity, distribution of energy, material flow circulation and the efficiency of the energy flow between trophic levels, etc.

In this study, two mass-balance models of Baiyangdian ecosystem were constructed using Ecopath for September and October 2009. It aims to inquiry the function and structure of Baiyangdian ecosystem changed before and after once anthropogenic water supplement in the middle of September 2009, and the changes in the trophic interactions, energy flow distribution in the trophic level, the status of the ecosystem development during the two periods were also compared.

Materials and Methods

Study area

Baiyangdian is located in the center of HeBei province, across AnXin, GaoYang, RenQiu, XiongXian, RongCheng five county's territory, with an area of about 366km^2 (standard level). Geographical coordinates is 38°43'-39°02' North latitude and 115°38'-116°07' East longitude. The pythmic elevation is about 5.5-6.5 m. The inflows conclude ZhuLong River, XiaoYi River, Tang River, Fu River, Cao River, Pu River, Ping River and BaiGou River. The average annual temperature is 7.3-12.7 degrees Celsius, and highest temperature is 43.5 degrees Celsius. The average annual precipitation in the whole basin is 563.7 mm, 80% of which focused on July-August, furthermore, interannual precipitation varies considerably. The average annual evaporation in the region is 1369mm, which is far higher than the average annual precipitation. When the water level falls below 6.5m, Baiyangdian Lake will dry out and the whole wetland will disappear when the water level falls below 5.5m.

The nutrient-enriched water and sediment provide high biological productivity and sustain important commercial fisheries. In Baiyangdian, common emergent aquatic plants include reeds (Phragmites australis), cattail (Typha angustifolia), and lotus (Nelumbo nucifera), and primary submerged plants are Ceratophyllales, myriophyllum aquaticum and pondweed etc. Common benthos animals include arthropods, mollusks, and annelids. Blue green algae and green algae are the dominant species in phytoplankton. Protozoa and rotifer are the main species of Zooplankton. Cyprinid Fishes are most, and crap and crucian occupy the largest proportion of fish yield.

Modeling approach

The trophic mass balanced model for Baiyangdian ecosystem was constructed based on Ecopath, which is part of EWE software, version 6.1 (Christensen et al. 2008), The software is developed by fisheries center in British Columbia University, and it could facilitate the establishment of energy balance model, determine trophic level of each function group, ecological nourishing flow transfer efficiency and other ecological parameters.

Ecopath model defines that ecological system contained a series of correlative functions (group or box). These components include organic detritus, phytoplankton, zooplankton, benthos, a kind of fish, a certain age group or the same ecological characteristics (such as feeding) of one fish. All the function components should generally cover energy flow in the system. According to the principle of thermal dynamics, Ecopath schema maintains the input and output energy in each biological functional group balanced, such as: production - predator death - other natural death - output =0. The model uses a group of simultaneous linear equations to define the whole ecological system. Each linear equation represent one function group.

mathematical formula expressed as:

$$P_i - B_i \times M_i - B_i \times (1 - EE_i - EX_i) = 0 \tag{1}$$

P_i is the production of function group i, B_i is biomass of function group i, M_i is predator mortality of group i, (1 - EE_i) is the other mortality for group i, here EE_i is ecological nutritional conversion efficiency, EX_i is i group output (including fishing quantity and amount). Equations (1) can be re-expressed as:

$$\mathrm{B_i} \times (\mathrm{P} - B)_i - \sum_j Bj \times (Q - B)_j \times DC_{ij} - \ (P/B)_i \times B_i \times (1 - EE_i) - EX_i = 0 \tag{2}$$

Or

$$B_i \times (P - B)_i \times EE_i - \sum_j Bj \times (Q/B)_j \times DC_{ij} - EX_i = 0 \tag{3}$$

According to equation (2), a model concludes n function groups can use the following simultaneous linear equations to describe:

$$B_1 \times (P/B)_1 \times EE_1 - B_1 \times (Q/B)_1 \times DC_{11} - B_2 * (Q/B)_2 \times DC_{21} \dots\dots B_n \times (Q/B)_n \times DC_{n1} - EX_1 = 0$$

$$B_2 \times (P/B)_2 \times EE_2 - B_1 \times (Q/B)_1 \times DC_{12} - B_2 * (Q/B)_2 \times DC_{22} \dots\dots B_n \times (Q/B)_n \times DC_{n2} - EX_2 = 0$$

……

$$B_n \times (P/B)_n \times EE_n - B_1 \times (Q/B)_1 \times DC_{1n} - B_2 * (Q/B)_2 \times DC_{2n} \dots\dots B_n \times (Q/B)_n \times DC_{nn} - EX_n = 0 \quad (4)$$

Here $(P/B)_i$ is production and biomass ratio for group i. $(Q/B)_j$ is the digestion and biomass ratio for group j, DC_{ij} is prey group i account for the total catch food of predator group j.

Ecopath software solve the linear equations to balance the energy flow among each function group, and calculate biological parameters of each component in the ecosystem. To establish Ecopath model, some basic parameters should be input: B, (P/B), (Q), EE, DC and EX........ In the first four parameters one can be unknown, and can be calculated by other parameters through the model, after two parameters, such as food matrix DC_{ij} and output EX_i is required to input.

The software defines the system is in steady-state, so biomass of each group does not change over time, the following equation must hold:

$$Q_i = P_i + R_i + U_i \quad (5)$$

where Q_i is consumption of group i, R_i is respiration of group i and U_i is unassimilated food of group i.

Input parameters and data

In order to guarantee the comparability of models for September and October, the two models were strictly constructed in the same manner, each including 14 function groups.

For each group, required input parameters are three of the following parameter B_i, $(P/B)_i$, $(Q/B)_i$, and EE_i. most of times, EE_i is difficult to estimate, it is usually unknown and estimated by the model (Christensen et al. 2005; Christensen et al. 2008).

The biomass data of phytoplankton, zooplankton, benthic and large aquatic plant are obtained directly from field measured data on September11th and October 12th. The biomass values of all fish compartments are adopted by assessment results of local fisheries Department. Partial production/biomass (P/B), consumption/biomass (Q/B) are calculated through empirical equations (Christensen et al. 2005; Christensen et al. 2008). For those groups whose P/B and Q/B do not have an empirical formulas are obtained from literature value in the similar ecosystem (Duan et al. 2009a; b; Li et al. 2009; Liu 1992), P/Q value is calculated through P/B and P/Q or used similar ecosystem study results; (Fetahi and Mengistou 2007; Yang 2003). Rough qualitative information is used to construct the initial diet composition of all groups (Cao et al. 2003; Cao and Si 1996; Mingde 1994). Then it is adjusted in order to make all ecotrophic efficiencies between zero and one.

Results and Discussions

Basic input and output

Ecopath calculates trophic level of each kind of biota according to their feed trophic level (often assume producers and detritus at trophic level Ⅰ) and the food composition weighted proportion.

Table 1 and 2 summarize the input parameters and the results of balanced trophic models for the Baiyangdian ecosystem in September and October 2009. The results demonstrate that the biomasses of mostly groups increased from September to October, but biomass of zoobenthos decreased distinctively, especially mollusks (from 14.5262 to 4.3063 tkm^2). The increase of biomass among other groups leading to the depletion of some groups may result in the reducing predatory pressure from predators or the weakening competition with other groups for food.

It is shown that the EE value for large aquatic plants were very low, especially in October, which of sybmery and emergy plants were EE=0.024 and EE=0.012, it indicates that most of the production of macroohytes are unconsumed and flowed into detritus and are buried in the sediment. The EE value for the detritus group decreased from 0.311 in September to 0.285 in October, suggesting that the detritus were not used effectively especially in October with great decrease in biomass of mollusea.

Table 1. Input and output (in italic) parameters of Ecopath model in Baiyangdian in September 2009

Group name	trophic level	biomass (g/m^2)	P/B	C/B	Ecotrophic efficiency	P/C
snakehead	*3.311*	0.706	1.300	7.000	*0.412*	*0.186*
Erythroculter ilishaeformis	*3.220*	0.471	1.500	7.900	*0.430*	*0.190*
Carp	*2.487*	3.531	1.900	8.800	*0.485*	*0.216*
Crucian	*2.227*	2.824	2.100	7.400	*0.645*	*0.284*
chub	*2.105*	10.592	2.300	8.500	*0.224*	*0.271*
Grass carp	*2.000*	3.531	2.500	9.000	*0.251*	*0.278*
fingerling	*2.320*	1.883	2.150	8.100	*0.927*	*0.265*
Mollusea	*2.329*	14.526	3.000	*12.876*	*0.193*	0.233
Microzoo benthos	*2.000*	4.487	20.000	*62.500*	*0.316*	0.320
zooplankton	*2.047*	4.138	113.000	*389.655*	*0.289*	0.290
Sybmergy plant	*1.000*	985.000	1.250	0.000	*0.027*	
emergy plant	*1.000*	174.042	1.000	0.000	*0.117*	
phytoplankton	*1.000*	23.390	85.891	0.000	*0.398*	
Detritus	*1.000*	20.636			*0.311*	

Table 2. Input and output (in italic) parameters of Ecopath model in Baiyangdian in October 2009

Group name	Trophic level	biomass (g/m^2)	P/B	C/B	Ecotrophic efficiency	P/C
snakehead	*3.311*	0.554	1.300	7.000	*0.412*	*0.186*
Erythroculter ilishaeformis	*3.220*	0.370	1.500	7.900	*0.430*	*0.190*

Carp	*2.487*	2.772	1.900	8.800	*0.485*	*0.216*
Crucian	*2.227*	2.218	2.100	7.400	*0.645*	*0.284*
chub	*2.105*	8.316	2.300	8.500	*0.224*	*0.271*
Grass carp	*2.000*	2.772	2.500	9.000	*0.251*	*0.278*
fingerling	*2.320*	1.478	2.150	8.100	*0.927*	*0.265*
Mollusea	*2.329*	4.306	3.000	*12.876*	*0.511*	0.233
Microzoo benthos	*2.000*	2.753	20.000	*62.500*	*0.206*	0.320
zooplankton	*2.047*	6.965	113.000	*389.655*	*0.204*	0.290
Sybmergy plant	*1.000*	874.274	1.250	0.000	*0.024*	
emergy plant	*1.000*	1297.164	1.000	0.000	*0.012*	
phytoplankton	*1.000*	29.508	85.891	0.000	*0.460*	
Detritus	*1.000*	8.248			*0.285*	

In table 1 and 2 the model calculated the trophic levels in decimal form as Odum (1975) suggested. There is another routing in Ecopath which can aggregate the entire system into discrete trophic level as Lindeman's (1942) suggestion. The aggregated discrete trophic level is also called the effective trophic level (ETL), ETL makes the food web more simplified, convenient for the analysis of energy flow through all trophic level and the efficiency of conversion.

The aggregation of biomass flow into ETL is listed in table3 and 4. In September and October the flows involved at trophic level V to VIII were very small, which could be neglected, thus in the two periods the ecosystem were simplified to four effective trophic levels.

Both In September and October, the biomass flow was mainly distributed in the first level and second level. However, the proportions of total system biomass at different trophic levels in the different periods were not the same. The biomass at TL Ⅰ increased from 1203t/km² (Sep.) to 2209 t/km² (Oct.), and at TL Ⅱ, Ⅲ, Ⅳ the biomass decreased from 37.39 to 27.19, 8.486 to 4.736, and 0.763 to 0.546 respectively.

Table 3. biomass distribution at effective trophic level in September

Trophic level	Living (t/km²)	Detritus (t/km²)	Total (t/km²)
VIII	0.000002		0.000002
VII	0.000076		0.000076
VI	0.00208		0.00208
V	0.0446		0.0446
IV	0.763		0.763
III	8.486		8.486
II	37.39		37.39
I	1182	20.64	1203

Table 4. biomass distribution at effective trophic level in October

Trophic level	Living (t/km²)	Detritus (t/km²)	Total (t/km²)
VIII	0.000001		0.000001
VII	0.000060		0.000060
VI	0.00150		0.00150

V	0.0324		0.0324
IV	0.546		0.546
III	4.736		4.736
II	27.19		27.19
I	2201	8.248	2209

The comparison of the throughput distribution in trophic levels

Energy flow directly influences ecosystem fundamental function, the structure and dynamics, the material circulation and information transfer. The total energy flow reflects the scale of ecosystem, which includes total of export, consumption, respiration and inflow to detritus. From table5 and table6 we can see that the respiration, consumption, flow to detritus and throughput tend to decrease despite the ascending trophic levels, according to pyramid distribution rule (Odum 1971).

Comparing the distribution of energy flow in September with that of October, it can be inferred that the total throughput increased by 42.88%, and flows to detritus increased by 44.92%. The throughput at TL Ⅰ increased distinctively.

The energy transfer efficiency among different trophic levels is also showed in table 5 and table 6. Both in these two phrases there are two food cycle chains: detritus food chain and grazing food chain. Comparing conditions in Sep. with that in Oct., the transfer efficiency at all trophic level Ⅰ, Ⅱ, Ⅲ, Ⅳ were declined, In the previous period the total transfer efficiency was 49.32% and in the ecosystem 37.92% of energy flow was through detritus food chain. In the later period the total transfer efficiency and the importance of detritus were basically similar to Sep., as 49.3% , 37.80% respectively.

Table 5. Distribution of throughput at discrete trophic levels in Baiyangdian ecosystem in September 2009

TL/ Flow	Import	Consumption by predators	Export	Flow to detritus	Respiration	Throughput	Transfer efficiency
VIII		0.000000	0.000001	0.000004	0.000008	0.000013	0.0769
VII		0.000014	0.000040	0.000179	0.000352	0.000585	0.0923
VI		0.00138	0.000887	0.00965	0.0151	0.0271	0.0837
V		0.0277	0.0193	0.200	0.316	0.563	0.0835
IV		0.574	0.332	3.769	5.843	10.52	0.0861
III		10.76	1.946	63.00	88.66	164.4	0.0773
II		168.4	9.165	849.6	1075	2102	0.0845
I	0	1936	2394	2560	0.000	6891	0.6284
Sum	0	2116	2406	3477	1170	9169	0.4932
Input TL II+ (not in throughput)						161.2	
Total throughput						9330	

Table 6. Distribution of throughput at discrete trophic levels in Baiyangdian ecosystem in October 2009

TL / Flow	Import	Consumption by predators	Export	Flow to detritus	Respiration	Throughput	Transfer efficiency
VIII		0	0.000001	0.000003	0.000006	0.000010	0.1

VII		0.000011	0.000031	0.000141	0.000276	0.000459	0.092
VI		0.00141	0.000697	0.0106	0.0152	0.0279	0.076
V		0.0282	0.0151	0.217	0.313	0.574	0.075
IV		0.579	0.261	4.172	5.891	10.90	0.077
III		11.02	1.528	68.87	89.34	170.8	0.073
II		172.7	7.196	1248	1486	2914	0.062
I	0	2641	3605	3717	0.000	9963	0.627
Sum	0	2825	3614	5039	1582	13060	0.493
Input TL II+ (not in throughput)						271.4	
Total throughput						13331	

Ecosystem attributes

Odum described the typical ecosystem development characteristic parameters qualitatively, And in Ecopath most of the parameters can be calculated quantitatively, Total primary production/total respiration (TPP/TR) is an important index to indicate ecosystem maturity. In mature ecological system, this ratio is approximately 1, illustrating that there is no excess product capacity for recycling systems. Finn's cycling index (FCI) states the proportion of system productivity contributes to the material and energy recycling, and shows that the flowing speed of organic matters in the ecosystem. When 0< FCI<1, the recycling rate is low, and the system is in its early development period. When FCI > 0.5, the recycling rate is enough high, the ecosystem is in the mature stage of development. The connecting index (CI) is the proportion of actual connections in the ecosystem to the total possible connections, the system omnivory index (SOI) is defined as the average omnivory index of all consumers weighted by the logarithm of each consumer's food intake (Christensen et al. 2008). Both CI and SOI reflect internal contact complexity in the ecosystem. When the system is more mature, The links of each function groups are stronger, and the indexes will be higher.

In September and October, the total biomass increased from 1403.823 to 3523.158 t•km^{-2}, and total net production increased from 1229.119 to 2233.45 t•km^{-2}. this means during this period, the system scale augmented obviously. In September TPR/TR, CI, SOI, FCI was 2.7778, 0.3155, 0.1203, 7.7, and in October, TPP/TR, CI, SOI,FCI changed into 3.1132, 0.3155, 0.1153, 6.15 respectively. Because the function groups was divided in the same way and diet composition of each group have changed little in the short term, CI was nearly the same in this two periods. Other indices such as SOI and FCI which reflecting the complexity of the inner linkage in the ecosystem, were lower than the value in Sep.. Generally speaking, both in the two periods, the primary productivity in the whole ecosystem was large, meanwhile the recycling rate was low, This means ecosystem have high excessive production, the connections of function groups are loose. The whole system is in immature period, and situation of September is relatively better than October.

Table 7. .Comparison of system statistics between the September and October 2009

Parameter	September	October
Sum of all consumption/(t•km^{-2})	2277.41	3096.549
Sum of all exports/(t•km^{-2})	2405.941	3614.071
Sum of all respiratory flows/(t•km^{-2})	1169.558	1581.815
Sum of all flows into detritus/(t•km^{-2})	3476.874	5038.862
Total system throughput/(t•km^{-2})	9329.783	13331.3
Sum of all production/(t•km^{-2})	4066.642	5819.93
Calculated total net primary production/(t•km^{-2})	3414.272	4924.506

Total primary production/total respiration	2.919284	3.1132
Net system production/($t \cdot km^{-2}$)	2244.714	3342.691
Total primary production/total biomass	2.7778	2.2049
Total biomass/total throughput/($t \cdot km^{-2}$)	0.1317	0.1675
Total biomass (excluding detritus)/ ($t \cdot km^{-2}$)	1229.119	2233.45
Connectance Index	0.3155	0.3155
System Omnivory Index	0.1203	0.1153
Total number of pathways	84	84
Mean length of pathways = Total number of arrows / Total number of pathways	3.74	3.74
Finn's cycling index(FCI)	7.7	6.15

Conclusion

Trophic models were constructed in September and October 2009, and the comparison between the trophic networks is used to quantify and analyze the trophic state and development stage of the ecosystem. The comparision of before and after one time anthropogenic water compensation in Baiyangdian is helpful to get further and integrated knowledge about the ecosystem response to water amount change.

Comparing the model results in September and October, the biomass at TL Ⅰ, the total throughput and flows to detritus are increased, meanwhile biomass at TL Ⅱ, Ⅲ, Ⅳ and transfer efficiency at lower trophic level are declined. The ecological indicators such as TPP/TR and SOI indicate the ecosystem‘s structure and function are weaken, and the situation in October is more vulnerable than September.

As the preliminary survey results shown above, after water supplement in middle September 2009, the ecosystem characteristic indexes have changed towards the bad direction further, although in the short term the variations are not very distinct. Now, more scientists have recognized that it is essential to discover the ecosystem response after anthropogenic water supplement and suggested water compensation must be based on the scientific inspect and verify, conform to the ecological law, think about natural seasonal regulation, reduce disturbance to ecosystem.(Cui et al. 2006; Wei 2005) , but the quantitative studies in this aspect is still few.

Baiyangdian ecosystem now is impressionable to extend interference, so the anthropogenic water supplement should be conducted with more consideration of the ecological rules and minimize the perturbation.

Acknowledgements

This work was supported by National Natural Science Foundation Grant for Distinguished Young Scholars (50625926), National Basic Research Program of China (973) (2006CB403303), National Natural Science Foundation of China (50909004, 50939001), Specialized Research Fund for the Doctoral Program of Higher Education (20090003120014) and National Water Pollution Control and Treatment Project (2008ZX07209-009).

References

[1] Bjelke, U., Bohman, I., and Herrmann, J. (2005). Temporal niches of shredders in lake littorals with possible implications on ecosystem functioning. Aquatic Ecology, 39(1), 41-53.

[2] Brock, M. (1991). Mechanisms for maintaining persistent populations of Myriophyllum variifolium J. Hooker in a fluctuating shallow Australian lake. Aquatic Botany, 39(1-2), 211-219.

[3] Brock, M., Smith, R., and Jarman, P. (1999). Drain it, dam it: alteration of water regime in shallow wetlands on the New England Tableland of New South Wales, Australia. Wetlands Ecology and Management, 7(1), 37-46.

[4] Brock, T., and Vierssen, W. (1992). Climatic change and hydrophyte-dominated communities in inland wetland ecosystems. Wetlands Ecology and Management, 2(1), 37-49.

[5] Bunn, S., and Arthington, A. (2002). Basic principles and ecological consequences of altered flow regimes for aquatic biodiversity. Environmental management, 30(4), 492-507.

[6] Cao, Y., Wang, W., and Zhang, Y. (2003). Present situation of fish stocks in Baiyangdian Lake. Chinese Journal of Zoology, 38(3), 65-69.

[7] Cao, Y. P., and Si, J. (1996). The Biology Analysis of Crucian Carp in Baiyangdian Lake after Restoring Water. Journal of Hebei University, 16(1), 53-58.

[8] Christensen, V., Walters, C., and Pauly, D. (2005). Ecopath with Ecosim: A user's guide. Fisheries Centre, University of British Columbia, Vancouver, 154.

[9] Christensen, V., Walters, C. J., Pauly, D., and Forrest, R. (2008). Ecopath with Ecosim version 6 User Guide. Fisheries Centre, University of British Columbia, Vancouver, 235.

[10] Coops, H., Beklioglu, M., and Crisman, T. (2003). The role of water-level fluctuations in shallow lake ecosystems–workshop conclusions. Hydrobiologia, 506(1), 23-27.

[11] Cui, L. J., Bao, D. M., and Xiao, H. (2006). Analysis on the eco-environmental water requirement and the water supply strategy of Zhalong wetland. Journal of Northeast Normal University, 38(3), 5.

[12] Duan, L., Li, S., Liu, Y., Moreau, J., and Christensen, V. (2009). Modeling changes in the coastal ecosystem of the Pearl River Estuary from 1981 to 1998. Ecological Modelling, 220(20), 2802-2818.

[13] Fetahi, T., and Mengistou, S. (2007). Trophic analysis of Lake Awassa (Ethiopia) using mass-balance Ecopath model. Ecological Modelling, 201(3-4), 398-408.

[14] Fischer, P., and Ohl, U. (2005). Effects of water-level fluctuations on the littoral benthic fish community in lakes: a mesocosm experiment. Behavioral Ecology, 16(4), 741.

[15] Haworth, R., Gale, S., Short, S., and Heijnis, H. (1999). Land use and lake sedimentation on the New England tablelands of New South Wales, Australia. Australian Geographer, 30(1), 51-73.

[16] Heymans, J., Shannon, L., and Jarre, A. (2004). Changes in the northern Benguela ecosystem over three decades: 1970s, 1980s, and 1990s. Ecological Modelling, 172(2-4), 175-195.

[17] Kingsford, R. (2000). Ecological impacts of dams, water diversions and river management on floodplain wetlands in Australia. Austral Ecology, 25(2), 109-127.

[18] Kusler, V. (2000). Climate change: potential impacts and interactions in wetlands of the United States. Journal of the American Water Resources Association, 36(2).

[19] Li, Y., Chen, Y., Song, B., Olson, D., Yu, N., and Chen, L. (2009). Ecosystem structure and functioning of Lake Taihu (China) and the impacts of fishing. Fisheries Research, 95, 309–324.

[20] Li, Y. H., CUI, B. S., and Yang, Z. F. (2004). Influence of hydrological characteristic change of Baiyangdian on the ecological environment in wetland. Journal of Natural Resources, 19(1),62-68.

[21] Liu, C., Xie, G., and Huang, H. (2006). Shrinking and drying up of Baiyangdian Lake wetland: A natural or human cause? Chinese Geographical Science, 16(4), 314-319.

[22] Liu, J. K., ed. (1992). Freshwater Aquacilture, Technology press, Beijing.

[23] Liu, L. H. (2005). Study on water resources carrying capacity and water environment of the Baiyang Wetlands. Master Dissertation, Agricultural university of HeBei, China.

[24] Liu, X. Y., and Lin, E., D. (2004). Impact of climate change on water requirement of main crops in North China. Journal of Water Conservancy(2), 77-87.

[25] McIntyre, J. (1994). Loons in freshwater lakes. Hydrobiologia, 279(1), 393-413.

[26] Mingde, L. (1994). Food web of fishes in Baiyangdian Lake. Hebei Fisheries, (001), 5-9.

[27] Odum, E. (1971). Fundamentals of ecology, 574 pp. Philadelphia: Saunders.

[28] Poff, N., Allan, J., Bain, M., Karr, J., Prestegaard, K., Richter, B., Sparks, R., and Stromberg, J. (1997). The natural flow regime. BioScience, 47(11), 769-784.

[29] Puckridge, J., Sheldon, F., Walker, K., and Boulton, A. (1998). Flow variability and the ecology of large rivers. Marine & Freshwater Research, 49(1), 55-72.

[30] Richter, B., Baumgartner, J., Wigington, R., and Braun, D. (1997). How much water does a river need? Freshwater Biology, 37(1), 231-249.

[31] Roberts, J., Young, B., and Marston, F. (2000). Estimating the water requirements for plants of floodplain wetlands: a guide. Occasional Paper, 04/00.

[32] Wantzen, K., Rothhaupt, K., Mórtl, M., Cantonati, M., Tóth, L., and Fischer, P. (2008). Ecological effects of water-level fluctuations in lakes: an urgent issue. Hydrobiologia, 613(1), 1-4.

[33] Wei, W. (2005). Regeneration of Phragmites communis Trin. in Zhalong Wetland and Ecological Water Supplement Analysis. Forest Inventory and Planning, 30(5), 4.

[34] Yang, Z. F. (2003). The sustainable development of fisheries and environment in Taihu Lake. Ph.D. Dissertation, East China Normal University, Shanghai, China.